Wetting Characteristics of Photographic Base Solid Polymeric Substrates

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Abstract

Wetting is the fundamental physical process in many industrial applications that include; film coating such as in pulp and paper, painting, printing, spraying, adhesion, enhanced oil recovery, composite processing and many more. The surface property of the coating on a given surface plays a vital role in terms of performance and service life. Significant effort has been made in the last three decades in improving the coatings on different materials. Achieving a uniform layer of coating on a given surface requires careful control and understanding of mechanisms that influence the spreading dynamics of the liquid. In this study the wetting characteristics of a number of substrates (used as photographic base material by companies like Agfa) has been studied and discussed. A total of three substrates are used in this study. A drop shape analysis method was utilised and drop spreading (in terms of contact angle and wetted drop base area) on the solid substrates were recorded using the FTA 188 video tensiometer. The test liquid was glycerine/water solutions of viscosities 49 mPa.s and 643 mPa.s and the surface tension was 65 mN/m. The results show that of the three substrates, one substrate shows low wettable characteristics and the other two show high wettable characteristics.

1. Introduction

Wetting which is a subject for studying the displacement of two immiscible fluids (generally, one fluid is gas/vapour, another is liquid) on a solid surface and is the fundamental process in many applications that include; coating, painting, printing, spraying, adhesion and many more [1-6]. Some of the applications of spreading of liquid drops on solid surfaces also include enhanced oil recovery, lubrication emulsions, photographic emulsions and plastics [7]. Applications such as handling of small liquid droplets, including selective permeability in a membrane and the operation of wall-climbing robots are also reported by [8]. Achieving a uniform layer of coating on a given surface requires careful control and understanding of mechanisms that influence the spreading dynamics of the liquid. Some of the fundamental methods by which wetting dynamics are experimentally investigated include the following: the spreading of a liquid drop on solid surface, forcing of a liquid to flow in a capillary tube, and moving a solid substrate into or out of a liquid tank.

Wetting is affected by many factors that include liquid properties, substrate properties and system conditions. Performing simple contact angle measurements can assess wettability of a surface. Contact angle (the spreading of a liquid drop with respect to time) technique is normally used in order to assess the wettability and adhesion of a surface. Wetting properties of different materials can be experimentally measured from the contact angle and liquid surface tension using Young's capillary equation as

$$\gamma_{sv} - \gamma_{ls} = \gamma_{lv} \cos\theta \qquad (1)$$

where γ_{sv} is solid – vapour interfacial tension, γ_{ls} liquid – solid interfacial tension and γ_{lv} liquid – vapour interfacial tension respectively.

Drop spreading is the most studied wetting processes from a fundamental viewpoint. Some of the recent work include that of [9] who studied partial wetting kinetics and applied it to the dynamic contact angle situations. The other relative work in this area is that of [10]. They studied contact angles with various liquids including silicone oils (also known as PDMS) and glycerine and tested with two of the existing models such as the molecular kinetic and the hydrodynamic model that describe wetting. They concluded that the data obtained with silicone oils could not be fitted to either of the two models. Some of the latest work includes that of [11] who studied dynamic contact angles with silicone oils but using a dip or free withdrawal coating method. They also measured the static contact angles of silicone oil on glass, aluminium and stainless steel plates using the sessile drop method and reported that silicone oil is completely wetting all three surfaces.

One of the objectives of the present work is to compare the wetting characteristics of three different polymer solid substrates with two liquids of different viscosities but same surface tensions. Wetting is assessed by means of obtaining contact angles and drop base area data with the two liquids and the three substrates under investigation.

2. Experimental Method

The Apparatus:

Figure 1 shows the experimental system. The system was very simple and consisted of a horizontal (with adjustable height) plate (1) onto which the test substrate (2) was placed. The liquid drop was created through the syringe needle (3) and placed on the solid surface. The process of spreading of the liquid drop was captured using a high-speed video camera (4) mounted parallel to the drop. These measurements were carried out at room temperature that was around 23 °C. For each experiment, the built –in software in the system would analyse the images for contact angle, drop base area, and drop height, volume and maximum diameter with time. Figure 3 shows the contact angle images (initial and final or equilibrium) obtained on the three substrates with glycerine/water solution sample1. Similar images were obtained with glycerine/water sample2. Each experiment was repeated at least twice and sometimes three times and the results presented here the averaged data for each experiment.

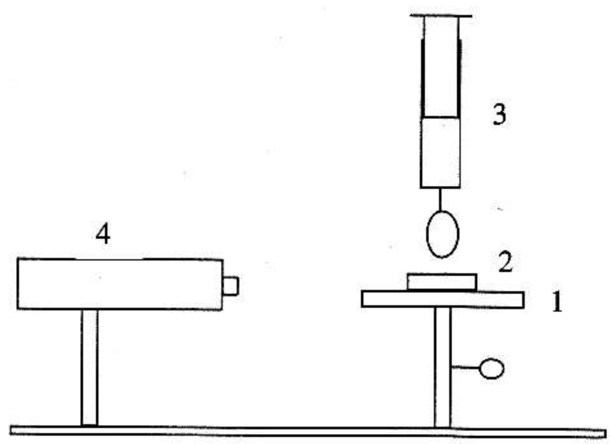


Figure 1: Experimental set-up

<u>The Coating Fluids</u>: In order to see the effect of liquid viscosity on wetting, we used two sets of glycerine-water solutions with viscosities 49 and 643 mPa.s and surface tension 65 mN/m in the experiments. The glycerines-water solutions were mixed at low speed for 24 hours with a propeller mixer and left to rest overnight prior to the experiments. With this standardized method of preparation, uncertainties resulting from undesirable effects such as absorption of air moisture by glycerin could be minimized. The physical properties of the liquids were measured at room temperature, which was around 23 °C. The viscosity of the fluids were measured to an accuracy of ± 5% in a Bohlin CVO viscometer equipped with a Peltier system allowing an accurate control (within 0.1 °C) of

the sample temperature. The viscosity was measured over a range of shear rates and temperatures and were found to be Newtonian as expected. The surface tensions of the fluids were measured to an accuracy of ± 2 % with a FTA 188 video tensiometer using the pendent drop method. The surface tensions were also measured at T_{exp} ± 0.1 °C and the density measurements were carried out using density bottle and the cylinder measurement methods. The physical properties of the fluids tested are shown in Table 1.

Table 1: Physical properties of the two liquids used.

Sample	ρ (kg.m^3)	σ (mN/m)	μ (mPa.s)
Glycerine/water sample 1	1203	65	49
Glycerine/water sample 2	1254	65	643

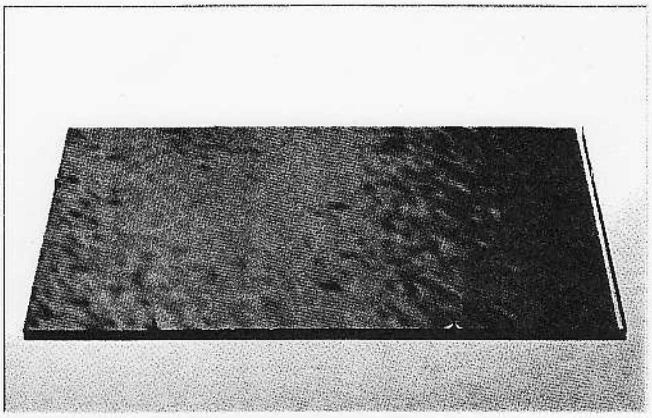
<u>The Substrates</u>: Two of the substrates (substrates 1 and 2) were provided by Agfa, Marlay in Switzerland. Substrate3 was purchased from HS insulations, Manchester, UK. All the substrates were tested as received without any prior modifications. The chemical composition of the substrates is not known and was not provided due to confidentiality issue. Substrates1 and substrate2 are being used as a base material in photographic industry while substrate3 is probably used in some insulation applications. The roughness of these substrates was measured using the Veeco, WYKO optical surface profiling system and the results obtained are shown in Figure 2.

3. Results and Discussion

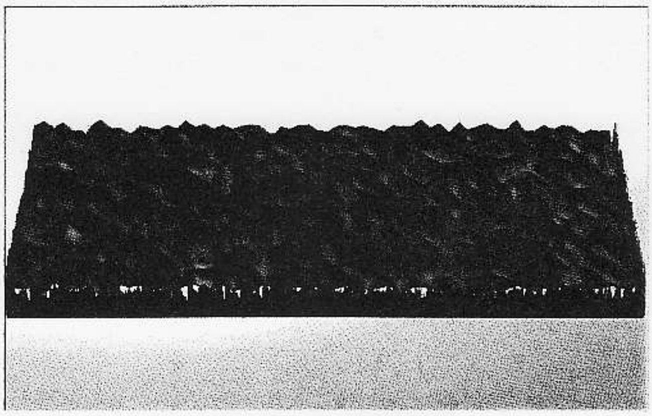
Results from the contact angle measurements for all substrates with glycerine/water solutions sample 1 and 2 are shown in Fig.4a and Fig.4b respectively. The results obtained with substrate1 suggest higher wetting characteristics as compared with the other two substrates. The contact angle variation curve is very closely followed by that obtained with substrate1. However, the variation in contact angle with substrate3 is not so significant also shown in Fig.3. Initially, when the drop makes a contact with surface of substrate3, it spreads quite rapidly and the contact angle drops by almost 10 degrees within the first minute of the spreading time and almost reaches an equilibrium state within two minutes. From this point onwards, the drop simply beads up and stays on the surface without any further spreading. This behaviour of substrate3 was observed with both sets of test solutions. One of the possible reasons for this behaviour may be due to its roughness, which may be causing the drop to rest on the peaks on the rough surface. As the roughness increases in Fig.2, the contact angles (initial and also final) also increases as highlighted in Fig.3. Viscosity effects on contact angles are more pronounced in the initial stages of the drop contact on the surface but seems to have little or no effect on contact angles in the later stages of drop spreading.

Figures 5a and 5b show the wetting characteristics in terms of drop base area evolution with time for all substrates with glycerine/water solutions sample1 and 2 respectively. Examining the spreading variation of the drops (in terms of the drop base area) on the three substrates, the drop covers more area with substrates 1 and 2 and takes quite a while before reaching an equilibrium whereas with substrate3, the area covered is quite small and the drop reaches an equilibrium in a very short period of time. As expected, the area covered by the drop with glycerine/water solution sample2, is initially smaller than the initial area of the drop with glycerine/water solution sample1. This was expected because the viscous forces tend to oppose the spreading and as a result, the initial drop base area with glycerine/water solution sample2 is smaller. However, the spreading patterns almost remain almost identical with both of the test solutions. Hence, lowering the viscosity will enhance wetting and spreading but many applications may require liquids with high solid contents i.e. high viscosity and therefore, lowering the viscosity may not be applicable. Another way to increase wettability is to choose substrates that are relatively smooth. However, this may require additional tools or preparation and finishing and therefore may not be economical.

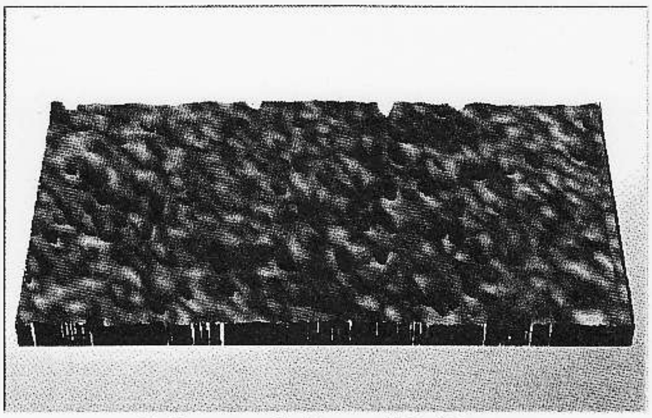
Figure 2: shows surface profiles of the substrates measured with the Veeco WYKO surface profiling system.



Substrate 1, Ra = 22.6 nm

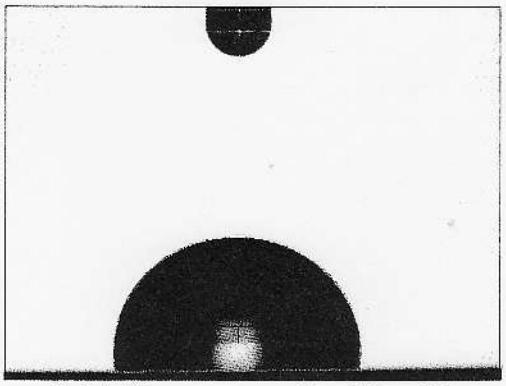


Substrate 2, 405.32nm

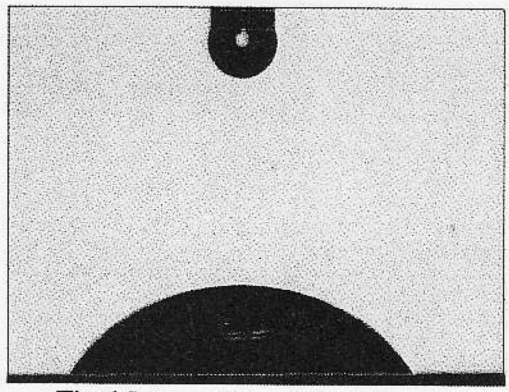


Substrate 3, Ra = 633.45 nm

Figure 3: Contact angle pictures (showing Initial and final) for all substrates with glycerine/water sample 1.

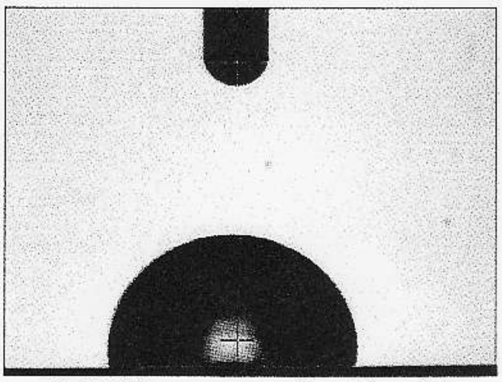


Initial Image, at t = 0s, CA = 94

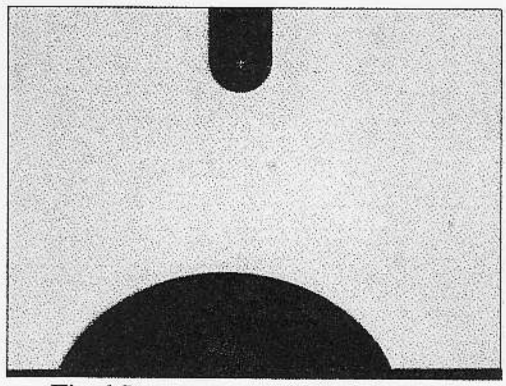


Final Image, at t = 27s, CA = 54

(Substrate 1)

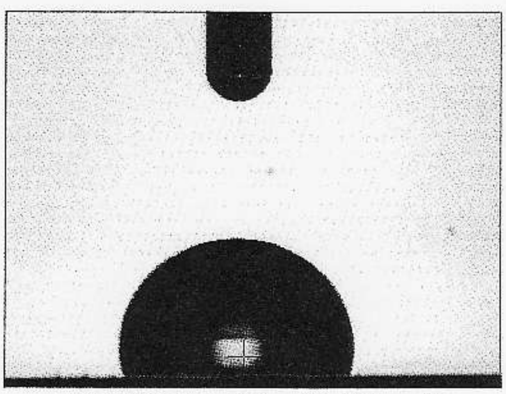


Initial Image, at t = 0s, CA = 93

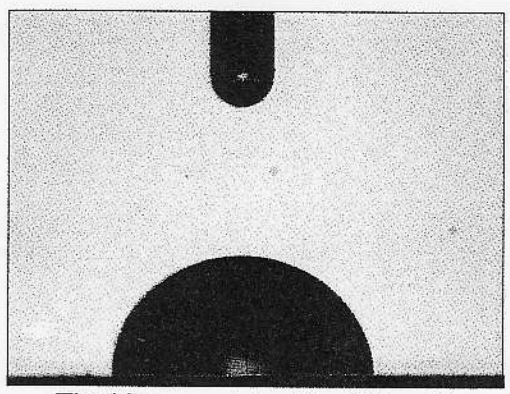


Final Image, at t = 27s, CA = 60

(Substrate2)



Initial Image, at t = 0s, CA = 99



Final Image, at t = 27s, CA = 84

(Substrate3)

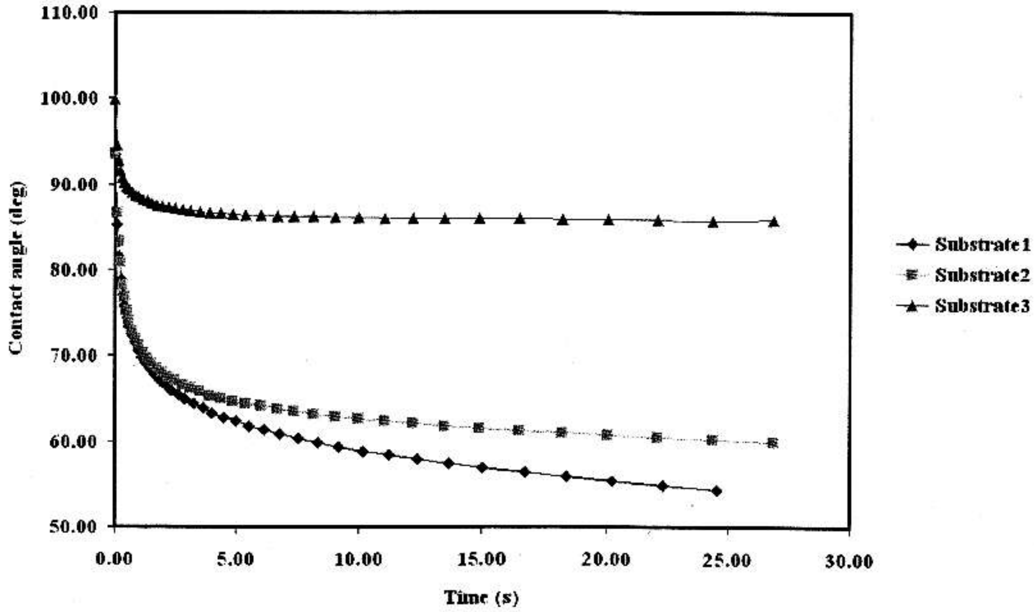


Figure 4a: Contact Angles on all substrates with Glycerine/water sample 1

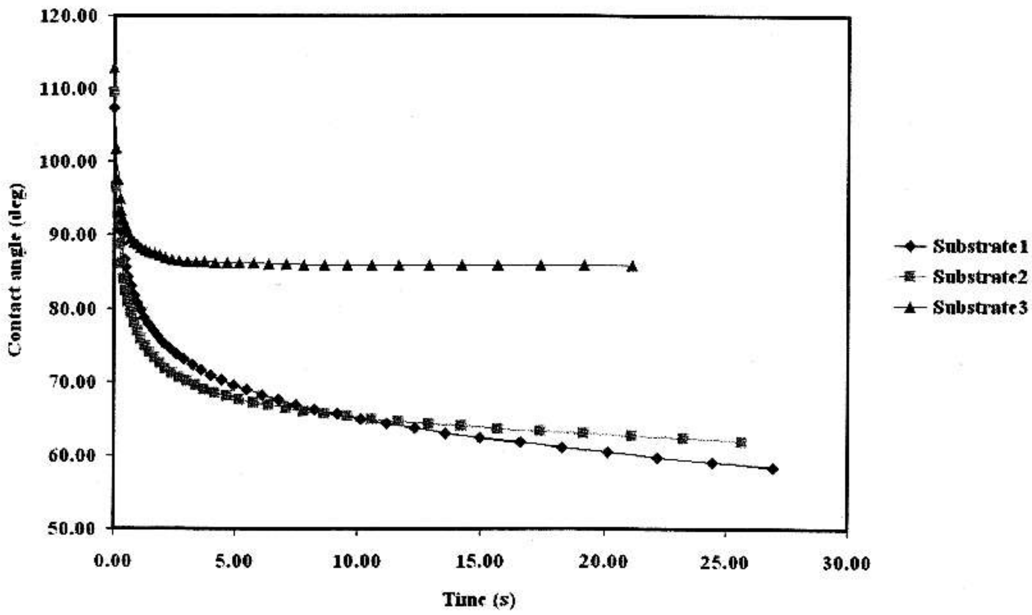


Figure 4b: Contact Angles on all substrates with Glycerine/water sample 2.

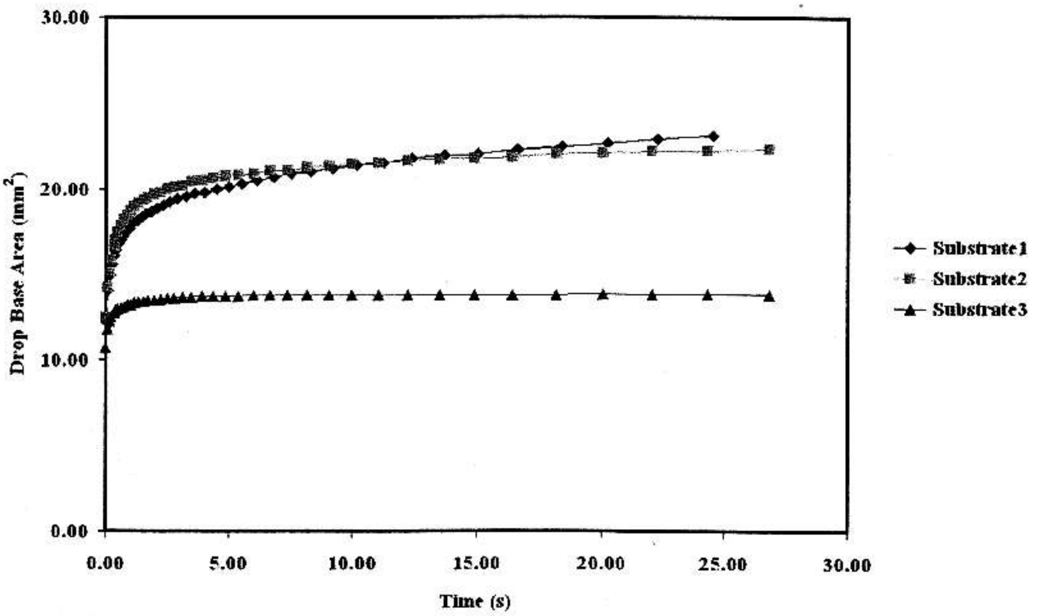


Figure 5a: Drop Base Area for all substrates with Glycerine/water sample 1

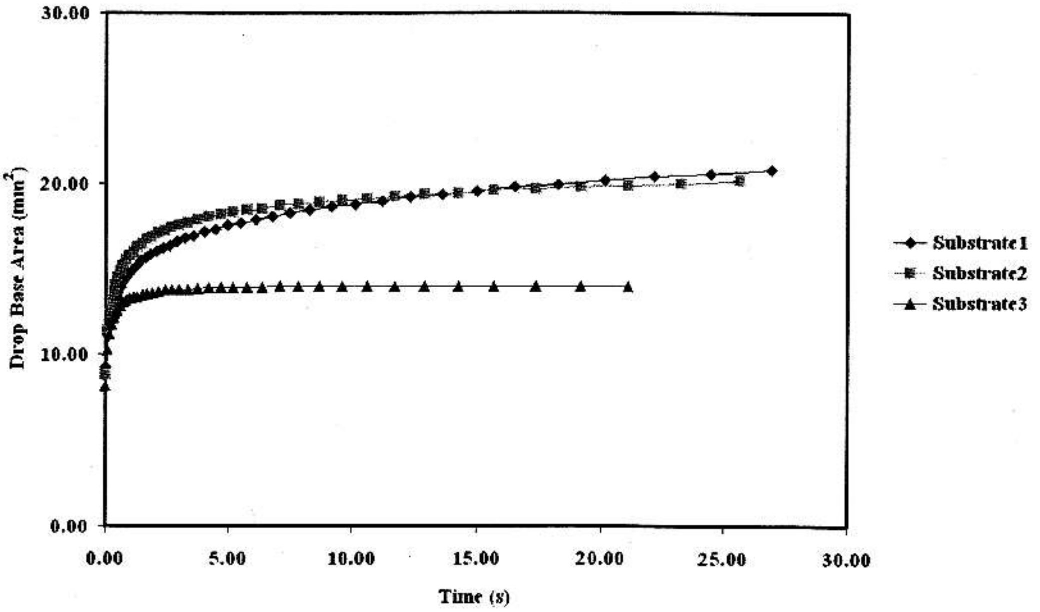


Figure 5b: Drop Base Area for all substrates with Glycerine/water sample 2

4. Conclusion

Surface properties play a vital role in the spreading process as observed with substrate3 and require an accurate characterisation of the substrate surface. Similarly, the liquid properties (viscosity in this case) also influence the wetting characteristics and therefore initiate the need for careful selection of the coating solutions. However, the viscosity effect is not so significant as compared to roughness.

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